Development and validation of a freezing pavement analysis to refine Alberta's winter weight policy

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Abstract. FPInnovations, in cooperation with the Canadian Forest Service, Alberta Transportation, Laval University i3C Chair, and the City of Edmonton recently completed a review of Alberta's starting threshold for initiating winter weight hauling. The threshold was 1 m frost depth but neither Alberta, nor any other jurisdiction, had undertaken a formal engineering analysis of the structural capacity of freezing pavements. The objective of this project was to determine the minimum frost depth at which hauling at winter weight premiums in Alberta could start without compromising pavement service life.

The paper describes the process used to develop a robust, validated, model capable of estimating the structural capacity of freezing highway pavements. This included analysis of freezing patterns in Alberta, resilient modulus testing of frozen roadbed materials, full scale accelerated trafficking test of two freezing pavements, and model development and validation. Based on this work, in December 2017, Alberta Transportation reduced the starting frost depth threshold used in its winter weight policy from 1 m to 0.75 m.

Substantial benefits to the public, forest industry, and the heavy haul industry are expected from a longer winter weight period and (or) a shallower frost depth threshold. The forest industry is predicted to realize $1.63M in haul savings for each additional week of hauling with winter weights. Given a shallower frost depth requirement, more participation in the winter weight program in the south of the Province and during warmer winters will be possible. The Province is predicted to see savings in pavement rehabilitation costs of between $1M and $2.5M per year arising from some truck volume moving from summer to winter.

Introduction. Winter weight premiums (WWP) allowed in some provinces help the forest sector increase yearly revenues and offset the impacts of spring load restrictions. It is proven that, given an annual volume of product to be transported, a modest increase in payload during winter can dramatically reduce trucking costs, as the number of trips decreases considerably (Yi et al., 2016). Alberta, Saskatchewan, Manitoba, Ontario, New Brunswick, and the Yukon and Northwest Territories currently have winter weight policies. Alberta offers the most generous WWP for log hauling trucks (Alberta Transportation, 2015) but also has the most conservative threshold for starting winter hauling (1 m frost depth).

FPInnovations, in cooperation with the Canadian Forest Service, Alberta Transportation, Laval University i3C Chair, and the City of Edmonton, undertook a review of the starting threshold for Alberta winter weights.

Objective. The objective of this research project was to make recommendations to Alberta Transportation regarding optimal frost depths in provincial highways prior to starting the annual winter weight log hauling programs. The objective was achieved with the following tasks:

- Document freezing patterns in Alberta highways through the case study of two provincial frost monitoring stations.
- Measure stiffness properties of unbound pavement materials from Alberta as they freeze.
- Develop a layered elastic modeling approach for freezing pavements using the freezing patterns and frozen material properties as inputs. Conduct preliminary modeling on the two cases studied sites to assess impact of freezing depth on key pavement strains.
- Validate the measured instantaneous stress and strain responses from the instrumented pavement at the University of Laval constructed to Alberta Transportation specifications.
- Validate long-term trafficking results of the frozen Alberta-style pavement to failure by using a strain-based service life model for frozen pavements.
- Establish the economic impact of changes to the WWP policy.
- Recommend a new starting frost depth for WWP based on results from this study.

Freezing patterns in Alberta. Alberta Transportation maintains a network of 68 thermistor stations with which they monitor the onset of freezing and thawing at highway locations across the province. At each station, there is a vertical array of 14 thermistors located in the pavement at standard depths that are from 5 to 300 cm; additionally a 15th thermistor is located at roadside to measure ambient air temperature.

Freezing patterns during the winter of 2016/17 were analyzed using the 25 thermistor stations located in mid-to-northern Alberta where the forest industry is active. Table 1 summarizes the average and range of freezing rates observed.

The average freezing rate during this winter was 3.3 cm per day, while the range was from 6.5 to 1.0 cm per day. Faster freezing rates can be expected in locations with warmer ambient temperatures, more south and south-west exposure, less snow cover, drier soils, and thicker asphalt and aggregate layers (Doré and Zubeck, 2009).

Table 1. Frost penetration rates observed in mid-to-north Alberta in winter 2016/17

	Time for frost depth to increase 10 cm (days)				Average freezing rate (cm/ day)
	from 60 to 70 cm	from 70 to 80 cm	from 80 to 90 cm	from 90 to 100 cm	
Average	3.2	3.6	3.4	3.1	3.3
Slowest	5.5	8.0	6.6	6.0	6.5
Fastest	0.9	1.3	0.9	1.1	1.0

FPInnovations summarized thermistor data for multiple winters from a north-west and north-east Alberta thermistor station (Wandering River and Grande Prairie, respectively) in order to derive typical freezing patterns for use with layered elastic modeling of freezing Alberta pavements. Figure 1 presents a summary of pavement freezing averaged for six winters from the Wandering River station. To the left of the figure is a scale diagram of the pavement structure comprised of 250 mm of asphalt mat and 300 mm of base course over subgrade.

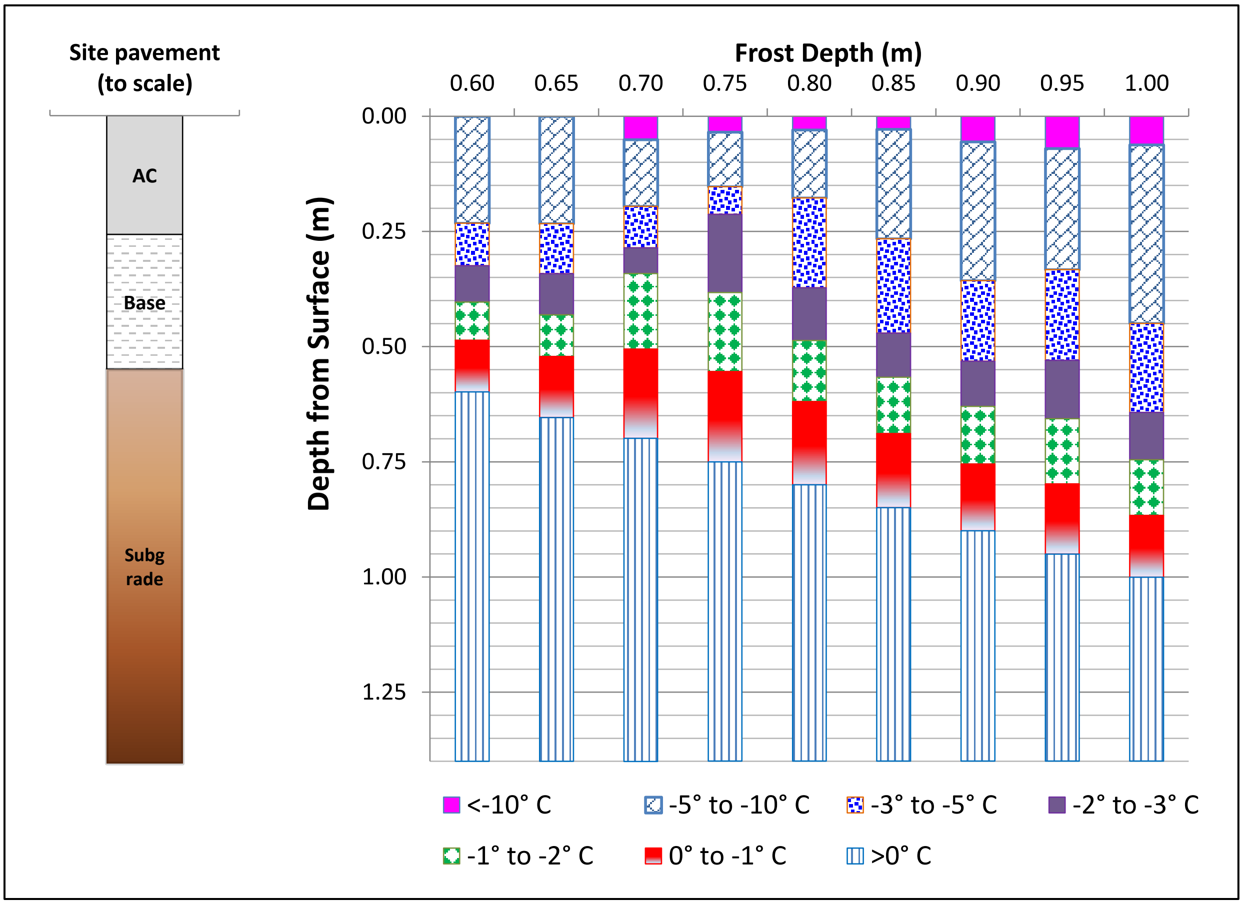

Figure 1. Typical freezing profiles at 9 frost depths, average of 6 winters, from Wandering River thermistor station (Thiam et al. 2018).

Frost depth increased steadily as winter progressed. At deeper frost depths, the near surface temperatures grew colder and dropped to below -10° C. The proportion of frozen material below -3° C grew also. At a frost depth of 60 cm, the asphalt mat temperature was between -5° and -10° C, while the base course temperature varied from approximately -4.5° C at the top to -0.5° C at the bottom. At a frost depth of 100 cm, the asphalt mat temperature was colder and varied from below -10° C at the road surface to –7° C at the bottom of the mat. Similarly, the base course temperature now varied from -7° C at the asphalt-base interface to -4° C at the base-subgrade interface.

Frozen pavement materials resilient modulus. Pavement subzero mechanical properties were measured at the engineering laboratory of the City of Edmonton (Kanji, 2015). Alberta Transportation identifed and supplied samples of three materials for testing: a 20 mm crushed granular base aggregate, a sandy clay till from Wabasca, Alberta, and a silty clay till from Fox Creek, Alberta. The granular base material was consistent with an Alberta Transportation standard base course specification. The subgrade soils were selected on the basis of them being representative of the low-to-medium plasticity clays typically found in Alberta's embankments. The test temperatures were selected to be representative of soil temperatures observed during early winter when Alberta pavements are freezing.

Testing comprised of soil classification (Atterberg Limits (ASTM D4318), Standard Proctor (ASTM D698), sieve analysis (ASTM C136), hydrometer analysis (ASTM D422)), sample preparation, and resilient modulus testing at five temperatures (5°, 0°, -2°, -5°, and -10° C) and two moisture contents (optimum and wet of optimum). The resilient modulus test method used in the study was AASHTO T307-99 (2007). Some minor modifications to test equipment and test method were necessary to generate consistent results at subzero temperatures. Resilient moduli for the base granular material and clay subgrade soils at various subzero temperatures were estimated from the range of values produced in Edmonton after resolving with representative pavement confining pressures in University of Laval's mechanistic empirical pavement design model (Doré et al., 2016). Figure 2 summarizes resilient modulus test results for the silty clay till and 20 mm aggregate samples, at optimum moisture content, as a function of temperature.

The silty clay till resilent modulus increased from 91 to 670 MPa as its temperature dropped to -10° C. Conversely, the aggregate dramatically increased in stiffness from 201 to 977 MPa at -2° C but, thereafter, showed no further increase. At -10° C, the silty clay and the aggregate samples were, on average, 736% and 453% stiffer, respectively, than at 5° C. Interestingly, both fine grained soils tested developed higher resilient modulii when wet of optimum than at optimum moisture content (i.e., at the wetter moisture content, these clay soils were weaker when unfrozen and stronger when frozen).

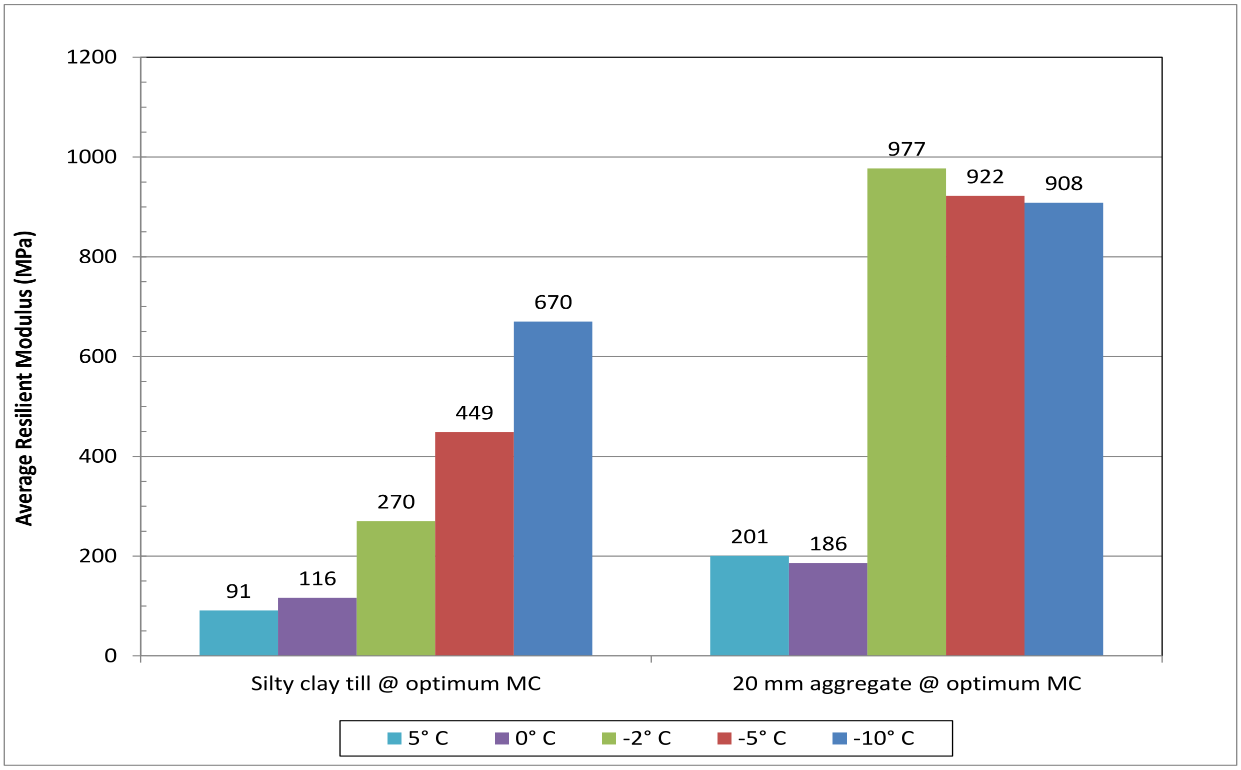

Figure 2. Resilient modulus of two unbound pavement materials as a function of temperature (Thiam et al. 2018).

University of Laval testing. Pavement testing was conducted between February and June 2016 at an indoor lab of the Civil Engineering Department of Laval University. The instrumented pavement was representative of an Alberta-style, flexible pavement and comprised 180 mm of hot mix asphalt EB-10S, and 300 mm of MG-20 (granular base equivalent to the Alberta 2-20 specification) on a low plasticity clay subgrade. Instrumentation included thermistors to record thermal profile, an optical surface deflection measurement device, strain sensors in the AC layer, and stress and strain sensors in the granular base and subgrade. Testing consisted of freezing the instrumented test pavement and, at regular intervals, measuring instantaneous responses to four different axle loads. Two freezing and trafficking cycles were conducted—the first with a water depth of 1.5 m below surface (representing drained subgrade conditions) and one with water depth of 0.8 m (representing a wet subgrade condition). Details of the test pavement construction and testing are provided in (Cloutier et al., 2017; Thiam et al., 2018).

To evaluate the impact of WWP, first the pavement baseline response was established by loading it with 4550 kg and 5000 kg loads under summer-like conditions. Summer-like conditions were obtained before freezing the pavement referred as t = 0 hour at room temperature with a stable water table. Stress and strain measurements made with Alberta's 4550 kg single axle legal loading under summer-like conditions are taken to be baseline references (hereafter referred to as measurements at *t* = 0). All results collected as the test pavement froze were normalized relatively to the reference measurements and expressed as relative values (RV):

$$\mathrm{RV}\ (\%) = \frac{\text{Value at t (all loads)}}{\text{Value at t} = 0\ \text{h (4550 kg)}} \tag{1}$$

Loading was varied between 4550, 5000, 5500, and 6250 kg and this corresponded to Alberta’s single-axle legal loading of 9000 kg, and three WWP single-axle loadings (10000 kg, 11000 kg, and 12500kg). These winter weight loadings were 10%, 21%, and 37% heavier than the legal loading.

In order to simplify the results presentation, only strains and surface deflections from freezing cycle 1 are shown in Figure 3. Freezing cycle 2 presented the opportunity to evaluate pavement response in a freezing pavement that had previously thawed. The results obtained in freezing cycle 2 were very similar to those from freezing cycle 1. As can be observed, there was a loss of data between 200 and 580 mm of frost penetration for the AC-RV strain sensor (green lines) which was caused by a temporary malfunction of the strain gauge. In addition, a mechanical problem was caused by a temporary malfunction of the strain gauge. In addition, a mechanical problem with the heavy vehicle simulator’s cooling system caused a brief thaw at a frost depth of 400 mm (t = 12 $h^{0.5}$), and this generated small increases in surface deflections and strains. To avoid damaging the pavement, no loads were applied until the hot mix asphalt mat was completely refrozen.

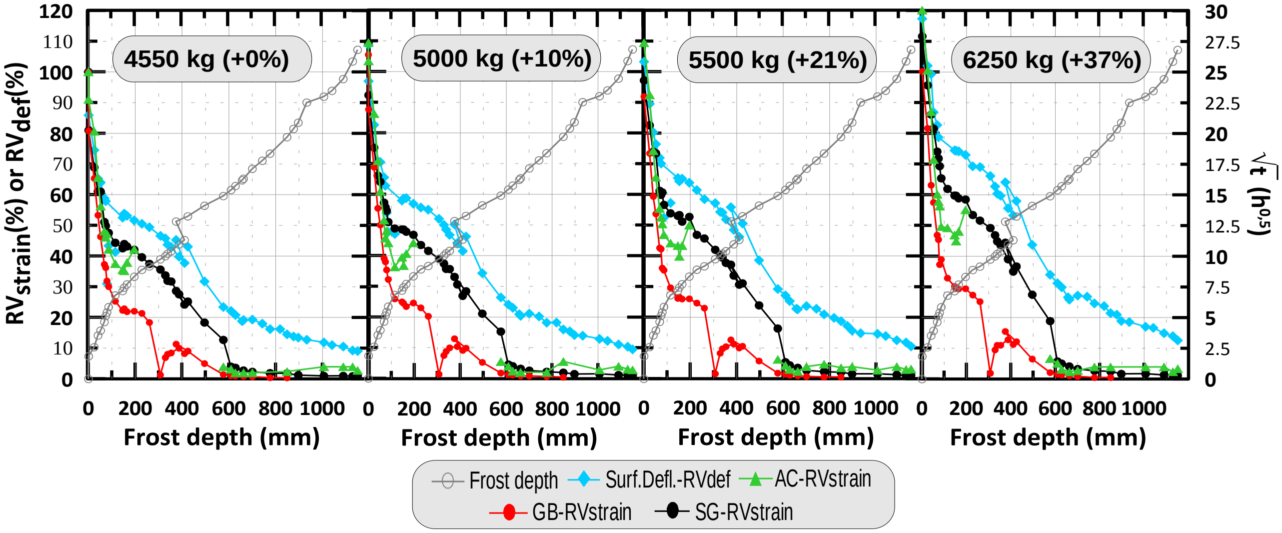

Figure 3. Relative value (RV) of response with respect to frost penetration and axle load (Cloutier et al. 2016).

The important structural influence of the bound surface layer is demonstrated by the rapid reduction in the surface deflection with decreasing asphalt temperature. When the frost had fully penetrated the asphalt concrete mat (at a frost depth of 180 mm) the relative values of maximum surface deflection were 53%, 58%, 65%, and 75% for loads of 4550, 5000, 5500, and 6250 kg, respectively. The pavement strains showed even greater RV reductions with freezing than did the surface deflections. The granular base course experienced the most substantial strain reduction when the hot mix asphalt mat froze, with a maximum relative value of 29% at the highest load (6250 kg). Following frost penetration of the hot mix asphalt mat, the relative values continued to decrease with freezing of the granular base and the lowering of the temperature of the hot mix asphalt mat. Once the pavement structure and the top of the subgrade were frozen (at a frost depth of 600 mm), the strain in all layers and the surface deflection were minimal. The surface deflection was the only parameter that continued to decrease as the frost penetrated the subgrade. These observations are similar to Ovik and Siekmeier (2004), who concluded that hauling with WWP could start in Minnesota, without risk of increased pavement damage, when freezing had penetrated 150 mm into the subgrade layer.

The effect of axle load on the mechanical responses of the freezing pavement is illustrated in Figure 4. All of the load-response comparisons were made using results from the first freezing cycle except for the AC-RV strain. The chart of load vs AC-RV strain was based on cycle 2 results because there was no loss in hot mix asphalt strain data during that cycle. For all pavement response parameters considered, the slope of the relation between RV and axle load decreases with increasing frost penetration, and this can be associated with the global increase of bearing capacity. At shallow frost depths, the effect of increasing axle load from 4550 to 6250 kg led to an increase of up to 20% in pavement response. When the frost depth reached 600 mm, however, increasing axle load resulted in negligible changes to all response parameters except surface deflection. Surface deflection increased, with respect to the 4550 kg case, by about 3% at the 5000 kg load, 6% at 5500 kg, and 10% at 6250 kg.

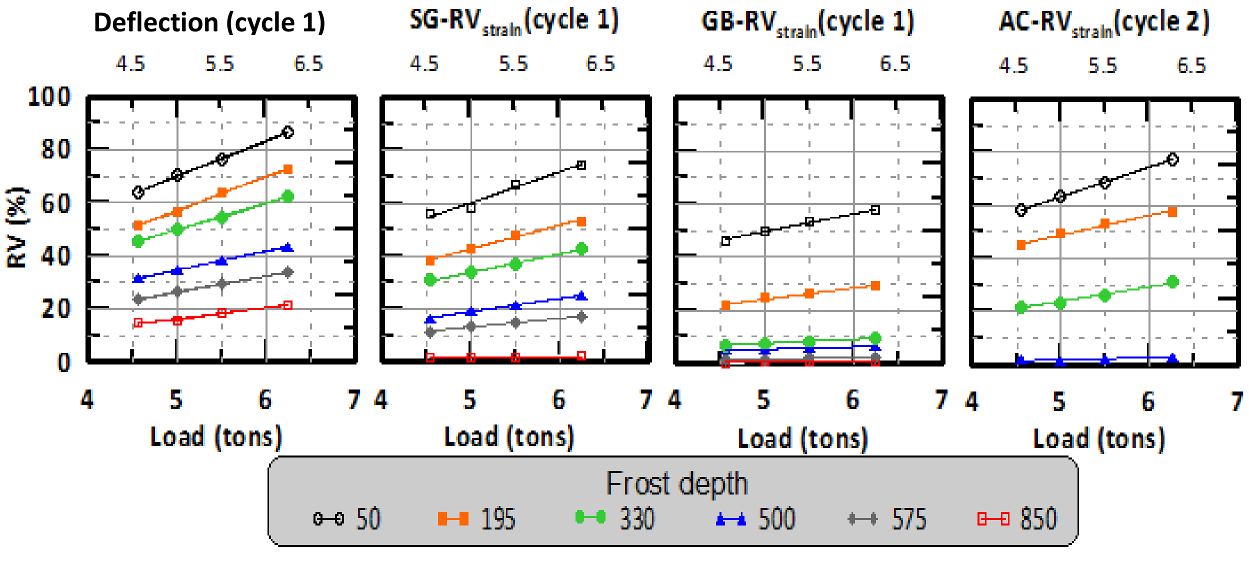

Figure 4. Load effect on relative values of pavement response (Cloutier et al. 2016)

Comparison to results from trafficking a freezing Quebec-style test pavement. A study of thawing pavements was conducted at Laval University in 2014-2015 for the Ministry of Transportation of Quebec (MTQ)(Yi et al., 2016; Bilodeau et al., 2014)). As part of the study, they measured pavement mechanical responses to half-axle loads of 5000 and 5500 kg during pavement freezing (prior to thawing the pavement). The test pavement was thicker than the Alberta-style pavement and consisted of 100 mm of hot mix asphaltic concrete, 200 mm of granular base, and 450 mm of granular subbase over a silty sand subgrade. The air temperature during freezing was the same (-10° C) for both studies and the water table depth was held at 1.6 m for the MTQ test.

Figure 5 and Figure 6 compare the results from this study with the MTQ test results. The results are expressed as relative strains at various frost depths with respect to responses to a 5000 kg load before freezing (t=0 mm). Similar trends were observed in both studies. Despite the differences in structure, the two pavements responded similarly to load increases during freezing. In both tests, under both loading conditions, the key pavement strains for fatigue cracking and rutting stabilized at a minimal value when frost depth reached 600 mm, and did not change much - if at all – at deeper frost depths or heavier axle loads. The differences in horizontal tensile hot mix asphalt strain and vertical compressive subgrade strain between the tests mostly can be attributed to the different hot mix asphalt thicknesses, subgrade soils, and water contents. The figures also highlight the effect of a 10% overload (5000 kg versus 5500 kg) which resulted in minor differences in strains for both test pavements.

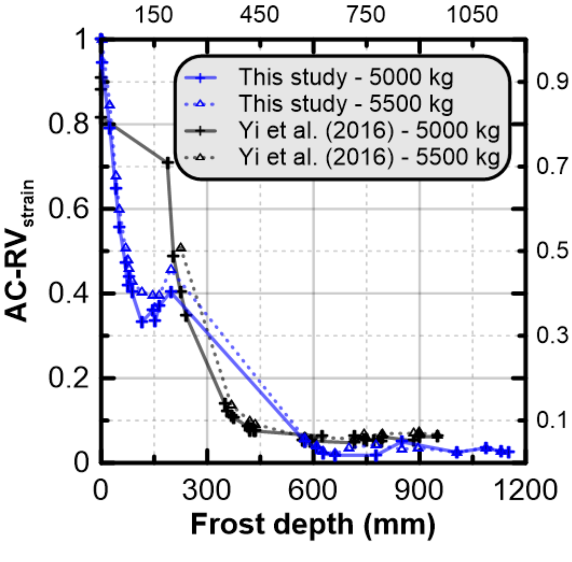

Figure 5. Relative values of AC mat horizontal strain with frost depth for two studies (Cloutier et al. 2016).

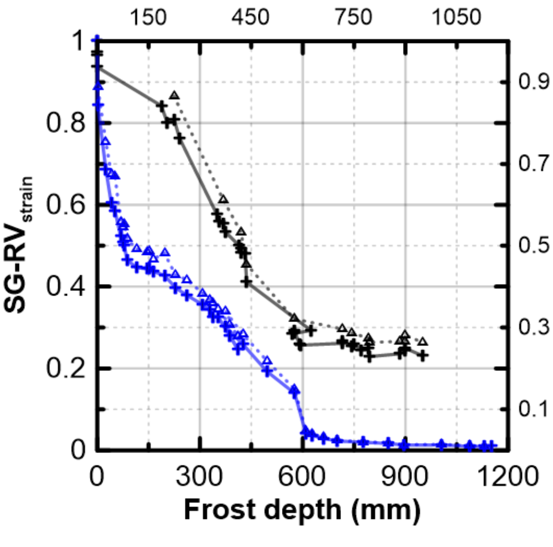

Figure 6. Relative values of subgrade vertical strain with frost depth for two studies (Cloutier et al. 2016).

Trends observed in lab testing of the Alberta-style pavement. The following conclusions were made about the load testing of the freezing Alberta-style pavement:

- A substantial reduction in pavement strains occurred before freezing, when the hot mix asphalt mat cooled and stiffened. By the time the hot mix asphalt mat was frozen, the underlying granular base course and subgrade strain responses to increased axle loadings had reduced by approximately 75% and 55%, relative to the strains caused by a legal load in summer-like conditions. Moreover, at a frost depth of 600 mm (when freezing had penetrated through the granular base and 120 mm into the subgrade soil), the strains were very small throughout the pavement (both relative to the reference condition and absolutely). Stiffening of the hot mix asphalt mat and freezing of the granular base appear to be the main factors associated with such a response.
- Except for surface deflection, pavement response to increasing load was negligible for frost depths of 500 mm or deeper.
- Based on theoretical estimates of fatigue cracking and rutting, predicted damage rates for the tested thin pavement became stable and negligible when the granular base was completely frozen, regardless of axle loading; Pavement responses to changes in freezing and axle loading were very similar in both freezing cycles.
- The same trends were observed with a thicker, Quebec-style, pavement tested in the same pit and under similar conditions in 2014/15.

Freeezing pavement modeling and validation with lab test results. The purpose of this phase of the project was to develop a linear elastic model of a freezing pavement that was validated with laboratory results from testing an Alberta-style pavement. This validation was accomplished by comparing estimated with measured spontaneous strain and stress responses.

Pavement subzero mechanical properties were measured by City of Edmonton testing of unbound pavement materials (granular base and silty clay subgrade)(Kanji, 2015). Additional modeling with Laval University's mechanistic-empirical pavement design guide (Doré et al., 2016) was required to resolve resilient modulus to a single value per temperature. The same loads used for the lab testing were used for the WinJULEA modeling. The frozen asphaltic concrete moduli were taken from the Witczak model in Level 3 of the MEPDG (NCHRP, 2011). Subsequent to testing, the asphaltic concrete moduli were evaluated by University of Laval and the values were comparable to the MEPDG values. Resilient moduli for the base granular material and clay subgrade at various subzero temperatures were estimated using the values measured by Kanji (2015), and resolving these with representative pavement confining pressures in University of Laval's mechanistic empirical pavement design model (Doré et al., 2016). Poisson's ratio values used in this analysis were based on MEPDG Level 3 ranges.

Figure 7 presents relative value results from the WinJULEA analysis and results from laboratory pavement testing, as a function of frost depth. Results were presented for 5000 kg and 6250 kg loads, and for both surface deflection and permanent strain at the top of the subgrade. Results showed great similarity between experimentally and theoretically (WinJULEA) derived relative values. As anticipated, the results showed a decrease in pavement sensitivity to loading with increasing frost depth. Firstly, as soon as the hot mix asphalt is frozen, an important decrease in relative values is noted. Then, as frost depth increases, deflections and strains decrease progressively. When frost depth reached 600 mm, both experimental and theoretical strain results decreased to very small relative values. Most importantly, the charts slope changes are similar—indicating good agreement between real life and modeling.

WinJULEA tends to overestimate pavement strains due to the approximation of materials' mechanical properties and this will result in an underestimate of cycles to failure. The number of load cycles, stress history, confining pressure, stress state, and degree of compaction can influence pavement mechanical response (Poupart, 2013). Some of these variables are not fully represented in WinJULEA and this may cause differences between modeled and measured results.

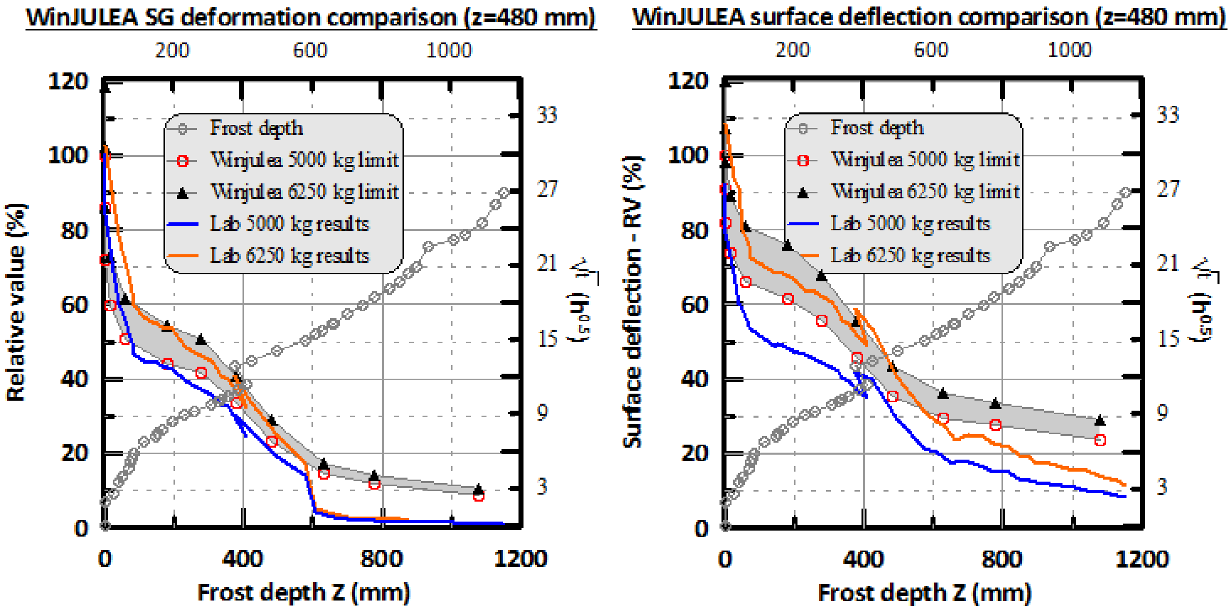

Figure 7. Comparison of subgrade strain and surface deflection, expressed as relative values of unfrozen conditions and a 4550 kg half-axle load, as predicted by a WinJULEA model and experimental test results (Cloutier et al. 2016).

Estimating load sensitivity of freezing pavement service life. In order to assess the effect of load sensitivity to freezing pavement service life, a damage analysis was performed using the test pavement structure and trafficking results. This analysis was focused on two performance parameters:

- Elastic tensile strain at the bottom of hot mix asphalt mat (maximum fatigue cracking criteria);
- Elastic compressive strain at the top of subgrade layer (maximum rutting criteria).

The estimated number of load repetitions to reach a failure condition in the hot mix asphalt mat and in the subgrade soil was calculated using the Asphalt Institute empirical transfer functions (Huang 2004):

$$N_f = C \times KF_1 \times \left(\frac{1}{\varepsilon_t}\right)^{KF_2} \times \left(\frac{1}{|E^*|}\right)^{KF_3} \tag{2}$$

$$N_r = KF_4 \times \varepsilon_c^{KF_5} \tag{3}$$

where, N_f is the estimated number of load repetitions to cause fatigue cracking over 10% of the wheel path, N_r is the estimated number of loads to cause a 12.7 mm-deep rut in the hot mix asphalt mat, ε_t is the horizontal tensile strain at the bottom of hot mix asphalt mat (mm/mm*), ε_c* is the vertical compressive strain in the top of the subgrade soil (mm/mm), $|E^*|$ *is the dynamic modulus of the AC (MPa),* C=0.07958, KF_1=1.0, KF_2=3.291, KF_3=0.854, KF_4=1.365x10^{-9} and KF_5=-4.477.

For each performance parameter, the theoretical pavement damage *(D)* induced in the pavement per load repetition was calculated as:

$$D = \frac{1}{N} \tag{4}$$

in which N is the estimated number of load repetitions to failure (N_f, N_r). The theoretical pavement damage was also expressed relative to the theoretical pavement damage from Alberta's heaviest legal half-axle load (4550 kg) allowed under summer-like conditions (D_{4550}*(*t = 0*))*. Relative damage*,* calculated for any frost depth (t), was defined as:

$$\mathrm{D(t)} \big/ \mathrm{D_{4550}(t = 0)} \tag{5}$$

Table 2 presents the predictions of bottom-up fatigue cracking and rutting, expressed as a percentage relative to that predicted for a 4550 half-axle load under summer condition. The results illustrate how freezing of the hot mix asphalt mat greatly reduced the predicted rutting. Conversely, when freezing reached the bottom of the granular base course, the predicted fatigue cracking damage was greatly reduced. At a frost depth of 500 mm, rutting and fatigue cracking from half-axle loads up to 6250 kg were predicted to be no more than 0.3% of that from a 4550 half-axle load under unfrozen conditions. From a service life perspective, at frost depths greater than 500 mm, the risk of pavement damage appears very minor even at the heaviest loading tested because the relative damage values were very small and they rapidly approached zero with increasing frost depth.

Table 2. Predicted fatigue cracking and surface rutting for various frost depths and winter weight premiums, relative to that from a 4550 kg half-axle load under summer conditions (Thiam et al. 2018)

Frost Depth	Fatigue cracking				Rutting			
	4550 kg	5000 kg	5500 kg	6250 kg	4550 kg	5000 kg	5500 kg	6250 kg
0 mm	100%	119.5%	not predicted		100%	149.1%	not predicted	
180 mm	41.6%	56.4%	72.5%	94.5%	3.2%	3.3%	5.4%	8.7%
300 mm	20.8%	23.5%	28.8%	58.8%	1.4%	1.5%	2.0%	4.0%
500 mm	0.05%	0.04%	0.06%	0.1%	0.1%	0.1%	0.2%	0.3%
600 mm	0.05%	0.07%	0.06%	0.10%	0.00%	0.00%	0.00%	0.00%
700 mm	0.04%	0.03%	0.07%	0.10%	0.00%	0.00%	0.00%	0.00%
800 mm	0.02%	0.04%	0.06%	0.07%	0.00%	0.00%	0.00%	0.00%
1000 mm	0.01%	0.01%	0.03%	0.05%	0.00%	0.00%	0.00%	0.00%

Sensitivity analysis. A sensitivity analysis, using a similar approach to described above, was conducted to assess whether the service life trends estimated for the test pavement could be expected to apply to the weakest Alberta highway pavement structures. An analysis of Alberta's highway pavement structures identified five representative weak pavement structures. Their total pavement thicknesses ranged between 235 and 360 mm (the test pavement was 480 mm thick) and all were underlain by a fine grained soil subgrade. The thermal profiles corresponding to different frost depths were taken to be that found with the multi-year analysis of freezing at Wandering River thermistor station (Figure 1). Figure 8 presents a comparison of WinJULEA-predicted strains, from a 6250 kg wheel load, in six, weak, freezing Alberta pavements (including the tested 'typical Alberta pavement').

Comparing relative strain values between Figure 8 and a similar analysis with a wheel load of 5000 kg, it was apparent that pavement load sensitivity, for the range of single axle loads considered, decreased with frost depth also, and became very small for all pavement structures by a 600 mm frost penetration.

It was concluded, therefore, that when frost depth reached 600 mm the strain levels became very small in all of the weak Alberta pavements studied in this project. Given that the analysed structures represented the majority of weaker Alberta provincial highway pavements, it was concluded that a single WWP starting frost depth could be adopted for the Province with confidence.

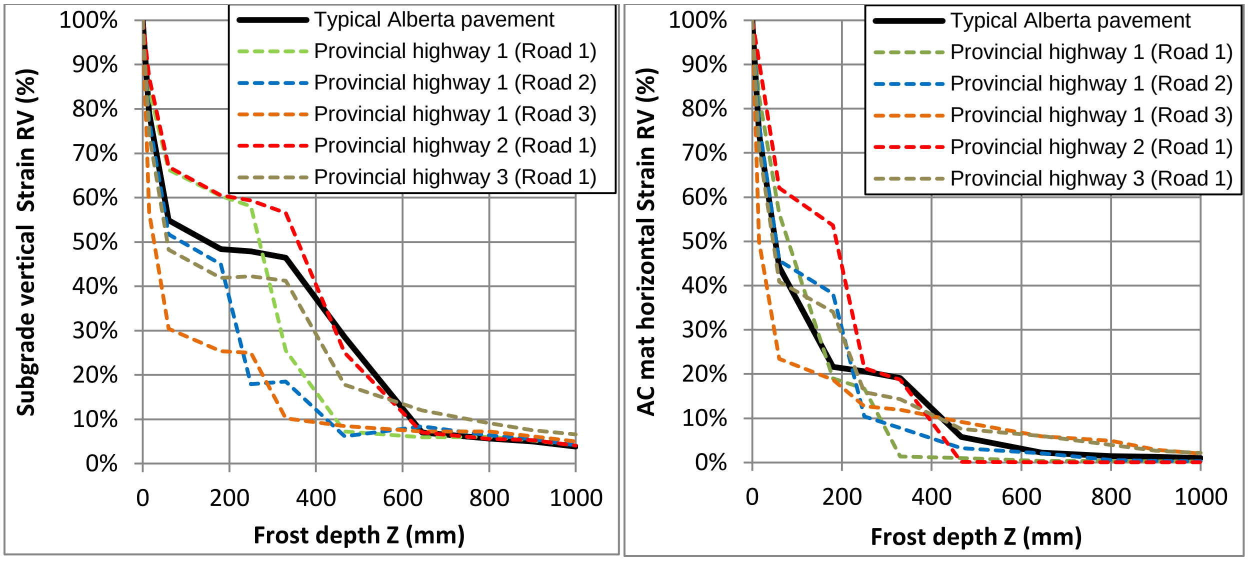

Figure 8. Predicted strain comparison for six, weak, freezing Alberta pavements including the tested 'typical Alberta pavement'. Subgrade vertical strains (left) and AC mat horizontal strains (right) from a 6250 kg wheel load are expressed relative to the strains from a 4550 kg wheel under unfrozen conditions (Thiam et al. 2018).

Implementation recommendation. Winter weights should be initiated, therefore, at a frost depth that typically corresponds to a time in winter when freezing proceeds steadily, and the pavement is well frozen and able to resist brief warming spells during the freezing process. This should lead to WWP staying on once they are instated causing less upset for both the forestry and heavy haul trucking, and regulators. Freezing pattern tests and data provided by Alberta Transportation indicate that initiating winter weights at a frost depth of 70 cm, as opposed to 60 cm, is more likely to result in colder roadbed temperatures and consistent freezing. This recommendation concurs with Ovik & Siekmeier (2004), who concluded that WWP hauling in Minnesota could start when freezing had penetrated 150 mm into the subgrade layer, without risk of increased pavement damage.

General benefits of winter weights. An important economic impact of a longer winter weight haul program is that it may prolong pavement life by encouraging more wintertime transport when road wear rates are a small fraction of summer levels. One estimate from a Saskatchewan Highways and Infrastructure executive was that Saskatchewan achieved 67% longer pavement life on its low volume pavements because of traffic impacts during the winter (e.g., 25 years of life with 15-year designs)[1]. Results presented in Table 2 substantiate this claim—frozen strain levels were a very small fraction of unfrozen pavement strains, regardless of the incrementally heavier wheel loads in winter. Thiam et al. (2018) estimates that substantial savings in pavement maintenance (in the order of $1M to $2.5M per year) would accrue if the starting frost depth for WWP were to be reduced to between 700 and 800 mm. Per Table 1, for

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[1] George Stamatinos, P.Eng. former Assistant Deputy Minister, Saskatchewan Department of Highways and Infrastructure. Personal communication. June 2001.

this range of starting frost depths the winter hauling period would be extended by 1 to 1.5 weeks.

Winter weights generate substantial economic benefits that increase the competitiveness of local truck-based industries, and help compensate industry for losses incurred from spring load restrictions. Policy changes to increase the length of the WWP period will further promote these benefits. Policies to encourage fewer, more heavily, loaded trucks increase the efficiency of hauling, thereby reducing GHG production, and reducing overall traffic levels.

The Transport Engineering Branch of Alberta Transportation manages the winter weight haul program in Alberta. They do not anticipate increased operating costs or other barriers to implementing a policy change to a shallower starting frost depth threshold for WWP.[2]

Forestry industry benefits of winter weights. Winter weight programs result in operational shifts from summer to winter harvesting and hauling. In the forest industry, where fixed volumes are hauled annually, starting WWP at a shallower frost depth allows companies to haul higher volumes per truck, and in total, under frozen road conditions. Higher winter payloads make for more efficient transport and reduce the cost of wood transport. FPInnovations surveyed its members to quantify the benefits of winter hauling, and a longer winter weight haul period. Haul savings at the current winter weight premiums were estimated by configuration, and extended from FPInnovations' member companies to the entire industry on the basis of processed mill volumes. If winter weight hauling were to start sooner, approximately $1.63 M per week in forest industry hauling savings is anticipated.

This earlier onset of winter weight hauling could occur with a policy change to a shallower starting frost depth. An analysis of frost penetration rates recorded at 25 AT thermistor stations during winter 2015/16 found that it took ten days, on average, for frost to penetrate from 700 to 1000 mm. Starting Alberta's winter weights at a frost depth of 700 mm, therefore, may result in 1.5 additional weeks of winter hauling, and incremental hauling savings to the forest industry of $2.44 M. In areas with wetter soils, or during years with wetter and warmer falls, freezing will be slower. Under these conditions, the time lag between 700 mm and 1000 mm frost depth will be longer than if conditions were dryer; therefore, the WWP period extension and predicted savings would be even greater. Additional, uncalculated benefits could accrue from a shallower starting frost depth because forest operations in the south of the province may now participate in the winter weight program—both in warmer years and in those areas that do not traditionally freeze to 1 m.

Increased opportunity to conduct winter weight hauling reduces the vulnerability of forest operations to climate change-induced interruptions due to wet weather, flooding, or wildfire in the summer. Transporting more wood in the winter with fewer trucks allows mills to reduce mill yard inventory volumes and costs, helps address driver shortages, and reduces summer traffic congestion on public highways hauling corridors.

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[2] Kim Durdle, P.Eng. Director, Transport Engineering, Alberta Transportation. Personal communication. May 2017.

Heavy haul industry benefits. The heavy haul industry is for the movement of non-divisible loads and is unlike the forest industry where higher weight translates into increased payload. However, heavy haulers do experience a benefit if they can transport loads with fewer axles (i.e., transport configurations are less costly and easier to manoeuver). Unlike the forest industry, heavy haulers have the advantage of a seasonal (fall) weight program so the increase to allowable winter weights is incrementally less. An early start to winter weights could mean an extra one to two weeks of hauling for some carriers, if the loads can't be hauled with enough wheels at fall weights. Like the southern forest industry, a big benefit could be to carriers in the south who were not able to participate in the winter weight program in the past because frost depths in the area did not reach 1 m. Crane carriers also would see an advantage as they are able to drop the boom dolly during winter moves, if there are no bridge capacity issues.

Policy change. In January 2018, Alberta Transportation announced a change in the starting and stopping thresholds for its winter weight hauling program. The starting threshold frost depth was reduced from 1.0 m to 0.75 m, and the ending thaw depth threshold was set at 0.25 m from a discretionary range of 0.25 – 0.3 m. The selection of a 0.75 m frost depth was in harmony with the winter weight starting frost depths in Saskatchewan and Manitoba.

Ready to adopt progress. A literature review conducted at the outset of the project found little information about the modeling of freezing and frozen pavements. Nor had Alberta Transportation or any other Canadian regulators conducted such an analysis. It is notable, therefore, that modeling the structural behavior of freezing asphaltic pavements using a layered elastic modeling approach was validated in this project. Layered elastic modeling closely predicted the patterns of strain recorded in the instrumented freezing pavement; however, the model conservatively overestimated strains by as much as 10%. This finding validates the use of layered elastic modeling for modeling freezing pavements and provides regulators and researchers with a useful tool for analyzing winter weight policies and the behavior of partially and well frozen pavements.

As noted, Alberta offers the most generous WWP for log haulers in Canada. These WWP are route and configuration specific and permitted axle weights vary from no increase to a sizeable increase. It was important for winter weight policy in Alberta in other jurisdictions, therefore, that the analyses assess the reduction in load sensitivity of freezing highway pavements. The full scale test results documented how, as ambient temperatures approached zero, the asphaltic concrete mat stiffened and dramatically reduced the strains felt in the pavement layers. Further, when both the asphalt mat and base course were frozen, their combined stiffness created a bridging effect that largely eliminated load sensitivity in the pavement.

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